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THE UNDERPINNING OF HEAVY BUILDINGS.

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WITH DISCUSSION.

This paper is a description of a novel method recently adopted for the support of heavy buildings.

The first instance of which mention will be made is in connection with the foundation work for the Commercial Cable Building, twenty-one stories high, at Broad and New Streets, New York City. The lot occupied by the new building is 45 ft. wide on Broad Street and 55 ft. on New Street, and is 160 ft. in length.

The plan required an unusually deep excavation which was to contain two stories below the level of the street, the total depth from the sidewalk to the under side of the concrete floor being 30 ft. on Broad Street and 36 ft. on New Street.

The lower story and a part of the next, being below the water level, had to be made water-tight, and in order to obtain that result the plan included, on each side of the lot, a continuous line of rectangular

caissons to be put in place by the plenum pneumatic process. Other caissons, circular in form, were also sunk in the central portion of the lot for the support of the middle rows of columns. There are 39 caissons, including those which are rectangular and circular.

All these caissons, the rectangular ones generally 9 x 18 ft. and 6 x 14 ft., and the circular ones from 8 ft. to 9½ ft. in diameter, were sunk to the underlying ledge which was found to be from 45 ft. to 50 ft. below the sidewalk. Fig. 1 shows the arrangement of all the caissons. The original soundings indicated that the surface of the rock was at a higher elevation, but actual excavation showed that it was lower than expected, and that an important layer of hard-pan from 5 ft. to 14 ft. in thickness must be gone through before rock could be reached.

The contract for the foundations contained the usual provision making the contractors responsible for any damage to adjacent buildings, resulting from their operations. This made it necessary to devise means for supporting the buildings, while the depth to be reached and the necessity for economizing space, where so many caissons and their accompanying coffer-dams had to be handled, made it important that as little room as possible be occupied by the supports necessary to maintain the surrounding buildings.

As compared with other work of the same class heretofore executed in that vicinity, the problem of supporting the adjacent buildings was unusually difficult in this case, as the plans provided for the placing of the rectangular caissons almost contiguous with one another and exactly on the boundary lines of the lot, an arrangement which had not been previously attempted.

The attention of the author had already been called to the fact that considering the increasing height of the buildings which are now being erected for business purposes on comparatively small areas, a limit would soon be reached beyond which it would not be economical, or even practicable or safe, to use timber supports, even of such special and ingenious design as have been recently adopted for such purposes.

The peculiar conditions under which the work had to be done in this case led to the conclusion that it would be desirable to resort to such devices as would leave the limited space at hand entirely free from interference, and open at all times for the free handling of the pneumatic, hoisting and other plants, for the movement of bulky caissons

and for placing them strictly on the boundary lines of the lot. This latter result was literally accomplished, the rivets of the steel caissons in their downward progress leaving, in many instances, their marks on the brick surfaces of the adjacent walls.

The method followed consisted of placing vertical iron supports directly under the walls to be supported in the following manner:

After determining the number of supports necessary for carrying the superincumbent weight, a vertical slit was cut into the wall from the bottom upward, for a distance depending on local circumstances, generally from 10 ft. to 12 ft., the slit being of such a width as would amply accommodate the pipe which had been determined to be sufficient in diameter for each case. On the top of that slit a short transverse horizontal cut was made, in which one or more iron I-beams

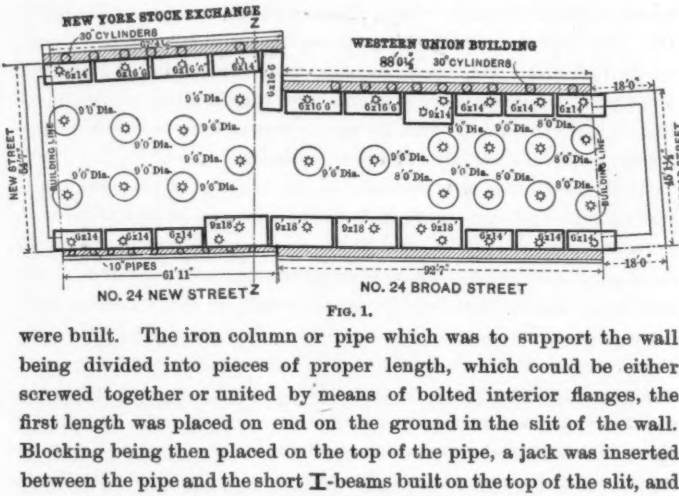

Fig. 1.

were built. The iron column or pipe which was to support the wall being divided into pieces of proper length, which could be either screwed together or united by means of bolted interior flanges, the first length was placed on end on the ground in the slit of the wall. Blocking being then placed on the top of the pipe, a jack was inserted between the pipe and the short I-beams built on the top of the slit, and either by simple pressure or with the aid of a water-jet, the first pipe was pushed down, by alternate jacking and blocking, to its full length. Next, a second piece of pipe was fastened on top of the first, and the sinking operation was resumed until another pipe could be added to the second, and so on until the pipe had reached bed-rock, or such other support as was sufficient.

The top of the highest pipe was left at about the level of the bottom of the wall, in which another set of short horizontal I-beams was

built, reposing on the top of the pipe. Vertical beams or columns were then firmly wedged between the two sets of horizontal I-beams, and the slit in the wall was filled up with brickwork. These vertical beams were used to avoid the compression which would otherwise occur in the fresh masonry built in the vertical slit.

Only one or two supporting pipes were, obviously, driven at a time, in order to avoid excessive concentration of weight on the other parts of the foundation while the pipes were being sunk.

The first trial of this method was made under the small building at the southwestern corner of the lot, it being desirable to proceed with caution. This building is only four stories high, but its brick wall was supported on a stone foundation of the worst description, 24 ins. thick, it being composed of small stones without bond, laid in so-called mortar without cohesion, which, at many places, could be easily blown off. The importance of keeping the building uninjured was increased by the fact that a restaurant business was conducted in the basement, and that an interruption of it would have caused a serious pecuniary loss to the contractors, who, as before stated, were held responsible for the proper maintenance of the adjoining buildings.

Considering that the distance of the bottom of the foundation wall of that building was 33 ft. from the hard-pan on which the supporting pipes were carried, and 23 ft. from the bottom of the cellar excavation intended for the new structure, the case required careful handling. Notwithstanding the small weight of the building, nine pipes were used on a total length of 57 ft. They are heavy steam pipes 10 ins. in diameter, ⅜ in. thick, having a cross-section of 12 sq. ins., and weighing about 40 lbs. per lineal foot. They were sunk in lengths of 5 ft., connected together with outside couplings and butt joints. Every alternate pipe contained a smaller interior one, placed so as to break joints, the annular space between them being filled with Portland cement grout. All the pipes were ultimately filled with Portland cement concrete. Each pipe was driven into the hard-pan to a firm bearing by working the jack to its full capacity of 60 tons, which is more than the weight that each pipe has to carry. No movement of any kind occurred during or after the sinking of the pipes.

The success attending this preliminary operation led to the adoption of the same method for the support of the buildings on the north side, the Western Union and Stock Exchange Buildings, with such

modifications and improvements as were rendered necessary by the greater weights of these structures, the Western Union Building being seven stories high and the other less.

The Western Union Building is built on piles extending about 17 ft. below the base of the walls, the points of the piles being consequently a few feet above the bottom of the new excavation. Nine pipes were sunk to support it. In this case it was found desirable to extend the supporting pipes to the rock bottom, thus making it necessary to force them through many feet of hard-pan, which could not be dis-

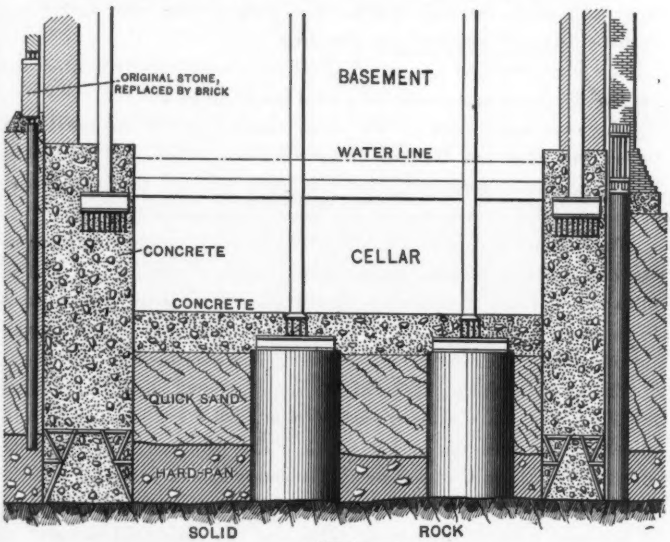

FIG. 2.

placed by jet and in which boulders might be found in the path of the pipes. In order to overcome these difficulties and to render it possible to level up the rock bottom on which the pipes were to rest, the pipes were made of cast iron, 28 ins. in interior diameter. This size made it practicable to send a man down for the purpose of excavating the hard-pan by hand in and under the edge of the pipe, of preparing intervening boulders for blasting, and of preparing the rock bottom when unsound or sloping and firmly wedging the bottom of the pipe thereon. Those operations, owing to the presence of water

in the ground, had to be carried on in compressed air, a portable and easily connected air-lock being provided for the purpose.

One of the lower pipes having been injured by forcing it down past a large boulder, the rest were subsequently made of riveted steel plates. Although boulders were encountered and blasted, and, in several instances, piles had to be extracted on account of their projecting into the lot of the new building, no serious difficulty was found in preparing for and sinking all the pipes, which were afterwards filled with concrete. Generally, two men, alternately jacking and blocking, were sufficient to drive the pipes, when once placed. No movement occurred in the Western Union Building.

The foundation of the Stock Exchange was similarly treated, six supporting pipes being used on a total length of 68 ft.

The next application of the same method was at the northwest corner of Cedar and William Streets for the support of the Stokes Building, a heavy structure, 11 stories high, pending the preparation of the adjoining foundation for the Queen's Insurance Building.

The Queen's Insurance Building is supported on pile foundations carrying grillages of steel beams which support the columns. The piles were cut off 1 ft. below the natural water level at the site, or about 18 ft. below the street level. The earth was excavated 1 ft. below the cut-off, and the concrete floor, 4 ft. thick, laid over the entire site.

The material at the site is of the same general character as often found elsewhere in the lower part of New York City, being quicksand underlaid by hard-pan and bed-rock. The preliminary borings indicated the existence of bed-rock 30 ft. below floor level.

The foundations of the Stokes Building are spread on the surface of the sand without supporting piles, and are estimated to carry 45 tons per lineal foot of wall. Unfortunately, when this building was constructed, the base of the foundation was placed about 2 ft. above the cellar floor of the adjoining building, now removed to make room for the construction of the Queen's Building (see Fig. 5). It was believed that the concussion of driving piles for the foundation of the Queen's Insurance Building would cause a flow of quicksand from underneath the wall of the Stokes Building, and consequently damage the structure.

The columns for supporting the Stokes Building are of cast iron, 33 ins. in exterior diameter and $1\frac{1}{2}$ ins. thick. When the work of placing

them was taken in hand, it was found that the borings were misleading, and the material supposed to be bed-rock proved to be firm hard-pan of considerable depth, in fact the first column was driven into it a distance of 16 ft. without finding any indication of rock. To persist in the attempt to reach bed-rock would have entailed an expenditure of a large amount of time and money without commensurate results, and it was decided to found the pipes on hard-pan. This material, being very compact, is capable of carrying a great load, especially at a considerable depth below the surface; however, as its limit of bearing

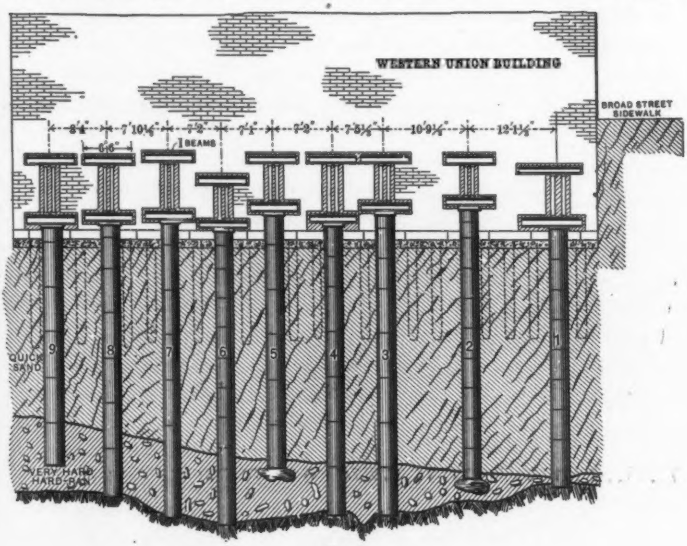

FIG. 3.

capacity is unknown, it was thought prudent to enlarge the base of the column by excavating outside the cutting edge and placing an annular steel ring on which the cutting edge was to rest. This ring, which extended 3 ins. outside the column and 4 ins. inside, was in sections and was composed of plates 1½ ins. in thickness.

The number of cylinders was not increased on account of the change in the foundation, and the pressure on the enlarged base, without deduction for friction on the sides of the columns, was in the neighborhood of 40 tons per square foot, which is, of course, much greater than

would be placed on masonry of the best character above ground. With due allowance for friction on the sides of the columns, the net load is supposed to be about 36 tons per square foot. Both these figures are doubtless in excess of the actual load, as the old foundation continues to bear some indeterminate part of the weight it formerly carried.

This work, including seven columns 33 ins. in diameter, was completed in seven weeks, without mishap of any kind, and the numerous piles for the new building were subsequently driven without injury to the Stokes Building.

Another high building, at the northwest corner of Wall and Nassau Streets, was also supported by similar means, the columns in that case being thirteen in number and made of lap-welded steel pipes $\frac{3}{8}$ in. in thickness and 16 ins. in diameter. This work was, it is reported, carried through successfully.

Referring to the illustrations (Fig. 1) gives the plan of the Broad Street foundation, showing the position of the 39 caissons and of all the pipes sunk under the walls of the adjoining buildings. Fig. 2 is a cross-section at a point where the lot widens. Fig. 3 shows the elevation of the rock bottom, the depth of hard-pan, and the position of all the supporting pipes. Fig 4 is a section of the supporting wall at one of the columns under the Western Union Building. Fig. 5 is a section of the wall of the Stokes Building, showing one of the supporting columns. Plate I is a view of the south wall of the Western Union Building, showing various phases of the operations for placing the supporting columns. Beginning at the right, the first, fifth and seventh columns are in place, and the operation completed. For the second and fourth, the cutting of the vertical slit is being made, close drilling being resorted to in this case, owing to the great hardness of the brickwork. At the third column the two sets of horizontal beams are in place, leaving only the vertical cut to be filled. The sixth column carries the air-lock while it is being sunk into the hard-pan.

Although the author does not wish it to be understood that the method above described is recommended as of universal application, he believes that in many cases, especially when the weights to be carried are great, and when the character of the ground is such that it becomes desirable to transfer the weight of the building to a deeper and

PLATE I.
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harder foundation, the new method is safer than those heretofore used and that it gives security economically. It has the advantage of leaving the ground which is to be built upon free from obstructions, thus preventing the costly and risky practice frequently resorted to of

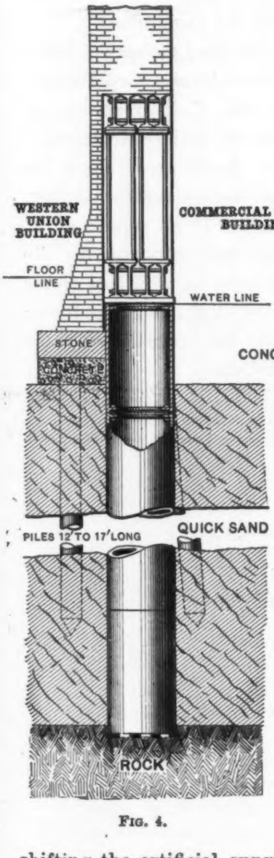


Fig. 4.

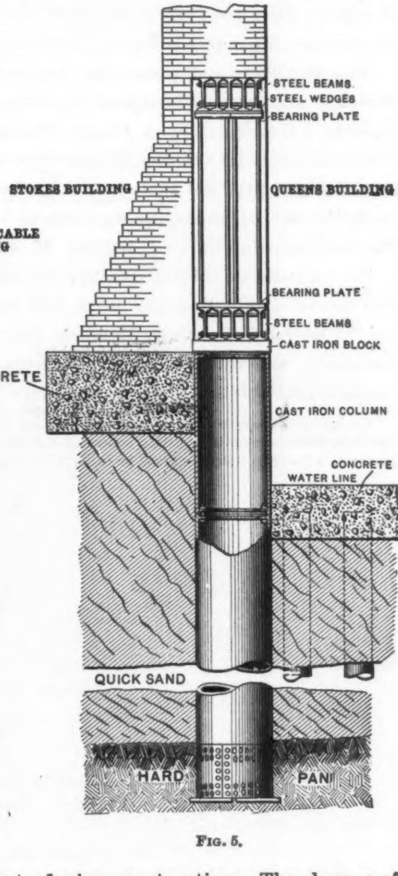


Fig. 5.

shifting the artificial supports during construction. The absence of interference with the inside of the adjoining buildings would often be a sufficient incentive to the adoption of this method; a lasting benefit can also be secured from the fact that the adjoining buildings remain

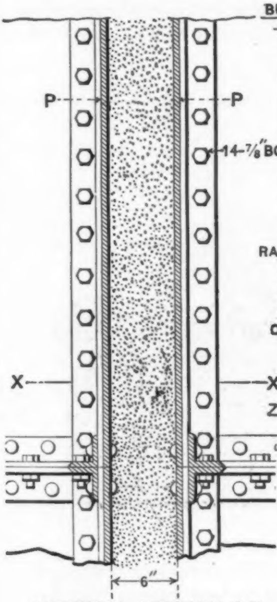
rigidly supported, thereby avoiding the usual, although often small, movements which follow the removal of the artificial supports used during the period of construction. Although other applications of the method may obviously present themselves in the general field of construction, the author prefers to leave others to draw their own conclusions, his object being only to describe the work done.*

The architects and consulting engineer for the Commercial Cable Company and Queen's Insurance Buildings were Messrs. Geo. Edward Harding & Gooch and John Bogart, M. Am. Soc. C. E., respectively. The contractors for the foundations were Messrs. Arthur McMullen & Co., of which firm the author is a member. In the execution of the work, the use of underpinning columns was devised by the author. The services of John F. O'Rourke, M. Am. Soc. C. E., were secured in the preparation of the preliminary plans and estimates for the Commercial Cable Building work, and the services of Alfred Noble and T. Kennard Thomson, Members Am. Soc. C. E., and Mr. Byron Goldsboro, superintendent, were secured for the operations on the Commercial Cable and Queen's Insurance Buildings.

* It has been thought unadvisable to burden this paper with too many details of construction, but if further information is desired, a detailed description of the foundations of the Queen's Insurance Building will be found in the *Engineering Record* of August 8th, 1896.

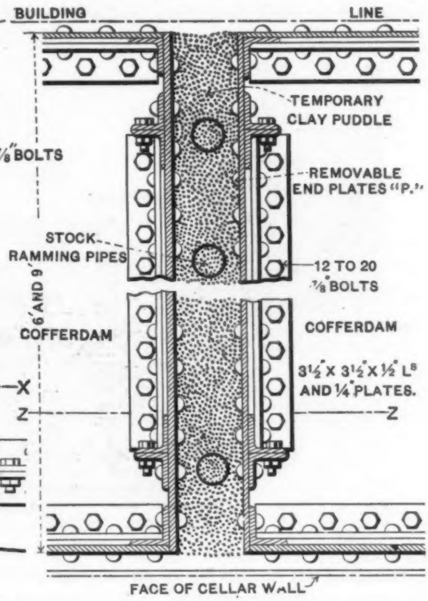
DISCUSSION.

Thomas Curtis Clarke, Past-President Am. Soc. C. E.—The paper lays before the Society the development or evolution of a new branch of civil engineering. The shoring of buildings because of excavations made beside them is a very old process, familiar to all engineers, but the depth of foundations and the want of room incident to the construction of modern lofty office buildings are such that the author found it necessary to introduce entirely different methods in such Mr. Clarke.



VERTICAL SECTION Z-Z.

Fig. 6.



PLAN AT X-X.

Fig. 7.

work, changing it from a mechanical craft to civil engineering. He made it scientific construction, which is civil engineering.

Frank W. Skinner, M. Am. Soc. C. E.—While the engineer who follows a successful precedent may be entitled to great credit for able construction and for accomplishing a difficult undertaking safely, he who establishes his own precedent, and that under particularly difficult circumstances, is certainly entitled to the greatest credit that can be awarded to an engineer for his construction. The author's method of underpinning foundations marks a new era in the very difficult work Mr. Skinner.

Mr. Skinner. which has become prominent within the last decade, and bids fair to be one of the important factors, if not the leading factor, of future construction in steel work. In the important engineering work connected with the foundations described in the paper, there were many features of interest which were not mentioned by the author. One problem submitted to the contractors was the construction of a large entirely water-proof cellar more than 15 ft. below the ground-water level. The rectangular caissons along the sides of the lot were extended above the water line by iron coffer-dams, set so close together as to form long side walls, and subsequently filled with concrete. They could not be sunk in contact, and a 6-in. space was left between adjacent caissons, which had to be temporarily calked in some way. It was

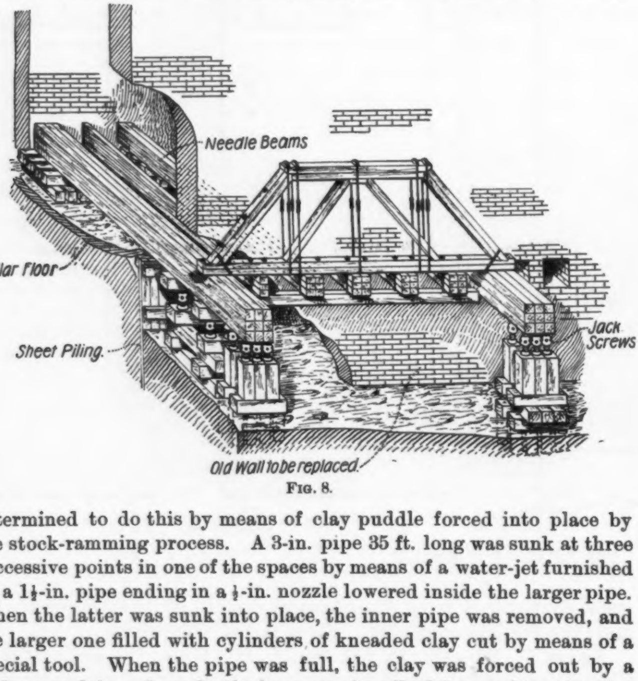
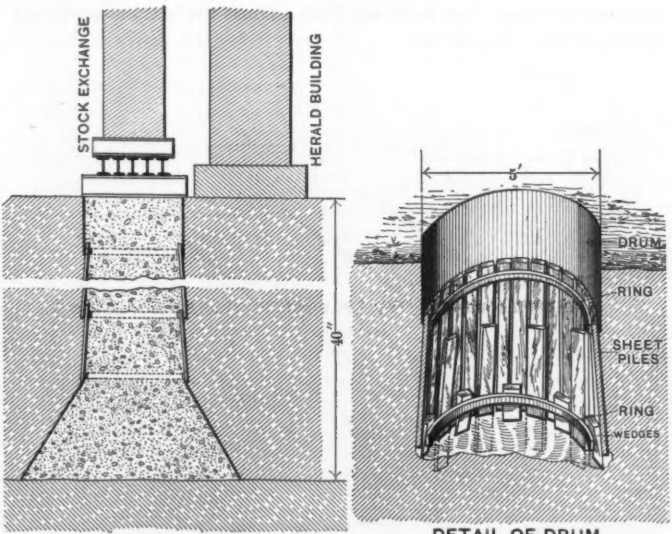


FIG. 8.

determined to do this by means of clay puddle forced into place by the stock-ramming process. A 3-in. pipe 35 ft. long was sunk at three successive points in one of the spaces by means of a water-jet furnished by a 1½-in. pipe ending in a ½-in. nozzle lowered inside the larger pipe. When the latter was sunk into place, the inner pipe was removed, and the larger one filled with cylinders of kneaded clay cut by means of a special tool. When the pipe was full, the clay was forced out by a 2¾-in. ram driven down by the hammer of a pile-driver. After the pipe had been filled three or four times, the ram had to be tapped a little in order to make it sink under the weight of the hammer. In this way from 3 to 5 cu. yds. of clay was inserted in each space. The pressure produced was so great as to shear the bolts in a number of the

flange splices of the removable end plates, *P P*, of the coffer-dams (Figs. 6 and 7). Mr. Skinner.

The manner of removing the débris from the bottom of the 10-in. pipes shown in Fig. 1, after the hydraulic jet had been used, was interesting. A long piece of gas pipe had attached to one end a sheet-iron cylinder which was provided on its bottom with inclined radial cutting edges like those of an auger. This was twisted into the material until full, and then lifted to the surface and its contents removed. When the pipe was cleaned out it was filled with concrete, the bottom 6 ft. being placed under water.



SECTION OF PIER

DETAIL OF DRUM, SHEET PILES AND STEEL RING

Fig. 9.

It has been mentioned that one of the advantages of the author's method of underpinning is the trifling obstruction it offers to the progress of work and the slight injury it causes to adjoining buildings. This is well shown by comparing it with one of the most ingenious expedients of the old method of shoring, which is illustrated in Fig. 8. In the construction of the foundations of a high office building in New York City, it was necessary to utilize all the site for conducting the operations on the new structure, and, indeed, a deck was built over it so as to gain additional working room. An L-shaped building bordered two sides of the site, and its walls had to be supported during the construction of the new foundations. A series of holes were cut

Mr. Skinner. through the wall just above the level of the basement, and built-up needle beams were inserted through them. These beams were formed of 12 x 12-in. timbers arranged as shown. The ends inside the basement were supported on distributing piers of cribwork, while the other ends were carried by a bearing beam hung from the bottom chord of a wooden truss. Each end of the truss was supported on heavier composite needle beams, which rested on cribwork at one end and at the other on blocking and jackscrews carried by piles, as shown in the cut. The rods by which the bearing beam was hung from the truss were provided with nuts which permitted some adjustment of the needle beams to be made. The truss was flush against the wall and projected from it perhaps 18 or 20 ins.

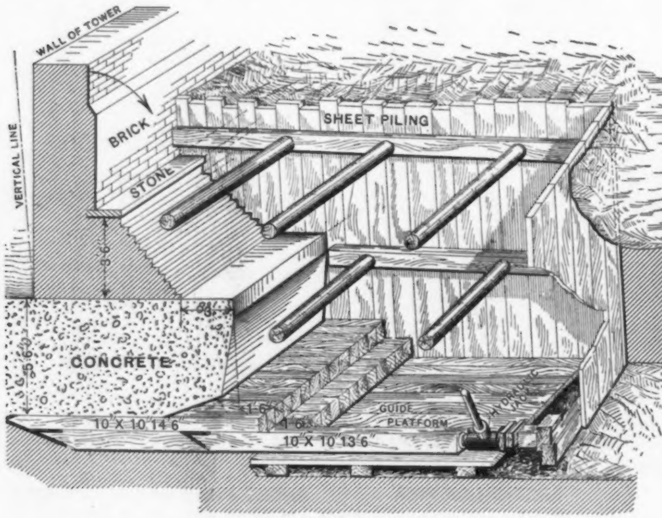


FIG. 10.

Eventually the cribwork at the outer ends of the end beams was replaced by small groups of piles which occupied very little of the ground space and left all that portion between them entirely unobstructed.

In the construction of the Stock Exchange Building in Chicago it was feared the excavation would injure the wall of an adjacent building, so it was underpinned in an unique manner by carrying down a series of intermediate piers from the wall to the hard stratum below. Cylindrical steel drums 5 ft. in diameter and about as high were set in cavities below the wall, and the enclosed earth removed. Short sheet piles were then driven under the bottom edge of the cylinder and the earth within this piling excavated nearly to its foot. Then a heavy

steel ring was set horizontally and another set of sheet piling driven between it and the first, as shown in Fig. 9. The earth within this set was excavated and the process continued until a well about 40 ft. deep was sunk to the hard bottom. The well was finally enlarged and filled with concrete. Mr. Skinner.

The method adopted to reinforce a long wall in Calcutta, India, affords another example of interesting foundation work. The High Court Building in that city has a front wall 379 ft. long and a tower of 45 ft. wide, and probably above 90 ft. high. It was built on the alluvial soil of that locality, and after twenty-five years was found to have settled unequally, the sinking amounting to more than 9 ins. under the tower, which was thrown out 11¾ ins. at one place 87 ft. above the ground. The face wall had also settled and inclined irregularly, but not to such an extent as the tower. Trenches or pits about 8 ft. wide and 22 ft. long were opened in front of the tower and wall, and carried down to the bottom of the concrete footing, which is about 13 ft. wide. The pit was sheet-piled and a timber platform built at a suitable level and very carefully made horizontal. A 4-in. auger was then driven horizontally below the footing to determine the form of its lower surface, of which no plans existed. It was found to be irregular, and many of these horizontal soundings had to be made to obtain the desired data. When this work was completed, the pit was excavated still deeper and a second horizontal platform was laid below the first on carefully leveled stringers. When this was finished, 10 x 10-in. piles, 14½ ft. long, were driven horizontally by 30-ton hydraulic jacks in the manner shown in Fig. 10. When a continuous row of these piles had been forced under the entire surface of the concrete footing exposed in the pit, a second continuous row was driven immediately below it. The piles of the first row projected about 18 ins. beyond the concrete footing, and those of the second row projected 18 ins. more, so that the two rows had the effect of widening the foundation of the wall about 3 ft. After this work was finished in one pit it was filled with earth and tamped, and another pit opened immediately adjoining it, the work being continued until the entire front of the wall and tower was underpinned. About five months were spent in the work on the 45-ft. base of the tower and eight months in that on the 380-ft. wall. The operations were intended to arrest the inclining of the wall and were manifestly powerless to straighten it.

The simplicity, economy and perfected directness and efficiency of the author's method is emphasized by comparison with an elaborate system employed by English engineers to arrest the settlement and partially restore the displaced walls of the Yarmouth City Hall. Here forty-four cast-iron cylinders in externally flanged sections were sunk on both sides of about 300 lin. ft. of wall, and a row of longitudinal iron girders was set on top of the cylinders, parallel to the wall, on

Mr. Skinner. each side. Numerous transverse beams 16 ins. deep were then put across the wall under its footing and screwed up to the longitudinal girders at each end by 2-in. suspender rods. Some rectification of the wall was accomplished by adjusting the screws, and a suitable trench having been dug, a new concrete footing was made to enclose the beams and girders and widen the base. The cylinders were 22½ ft. long, 1⅜ ins. thick, and 30, 36, 54 and 60 ins. in diameter, according to the weight of the adjacent wall; all of them were filled with concrete. The work was accomplished in twelve months at a cost of $41 000.

Mr. Bogart. JOHN BOGART, M. Am. Soc. C. E.—A few more words may be added to the author's statement that the contractors were responsible for any damage to adjacent buildings, resulting from their operations. The law requires the owners of a new building to take care of existing adjacent buildings, provided only that the foundations of these buildings are at a certain depth below the curb. Under these circumstances it was deemed proper that the contractors for the foundations of the new building should do whatever might be necessary to take care of the adjacent structures, and they were therefore requested to assume that care and responsibility, including in their tenders a sufficient sum to pay for such service.

The author shows in Fig. 5 a section of the foundation of the Stokes Building, which is so built that the line of pressure of the wall on the concrete is not centered, and consequently produces tension in the base, evidence of which was detected during the progress of the work. This base had its bottom over 2 ft. above the floor of the cellar of the old adjacent building and was founded on sand. The water level was at, or a few inches below, the floor of the cellar of the latter, and nothing kept the sand from running except a small brick wall, part of which was merely the wall of an area.

The experience gained during the progress of the work described in the paper proves that when cylinders are used to support structures of any size where work is to be done immediately adjacent to them, these cylinders should be large enough in interior diameter for reasonably comfortable access, both for working and for careful examination. All the cylinders in the work described were examined frequently during their sinking by an engineer, who went in each instance to the bottom of the cylinder. Borings had been made in adjoining cellars as near to the proposed location of the cylinders as possible, but their indications were misleading. As a matter of fact the original scheme for the foundations of the very heavy Queen's Insurance Building had to be changed on account of discoveries made during the sinking of the cylinders, which showed that the conditions were different from what were apparently indicated by the borings. Another reason making it important for an engineer to be able to examine the work is the fact that the reports of men laboring in such small cylinders under fairly heavy air pressure are not always reliable as to the character of

the ground at the bottom. Solid hard-pan was several times reported, but when an engineer made an examination, his bar went through the hard pan and was nearly lost. In another case when solid rock was reported, it turned out to be a boulder of moderate size which was broken up and taken out, the cylinder afterwards being pushed much farther down. Mr. Bogart.

This method of transferring the weights of structures to rock or other reliable bearing, even when such bearing exists only at a considerable depth, has greatly lessened the difficulties and dangers connected with the erection of heavy buildings adjacent to other structures whose foundations are unsatisfactory and not to be depended upon when deep excavations must be made in their immediate vicinity.

Henry B. Seaman, M. Am. Soc. C. E.—It has been stated that there was evidence of tension in one of the old foundations exposed during the progress of the work. It should be explained of what this evidence consisted, whether it was the presence of cracks, or merely the fact that the line of pressure did not fall within the inner third of the foundation. The latter condition is usually assumed to produce tension, and may be very generally found in retaining walls, but no tension exists, nor can exist, without a tie. So long as the distance from the line of pressure to the near side of foundation is sufficient to withstand one-half the load, without settlement, there will be no tension, nor even cracks, in the foundation. Mr. Seaman.

John F. O'Rourke, M. Am. Soc. C. E.—The author calls attention to the very heavy weights that can be borne by hard-pan, a fact proved by experiments made while underpinning the walls of a building in New York City in the manner described in the paper. The pipes had a cross-section of about 20 sq. ins., and were provided at the bottom with a reinforcing ring which gave the bottom of the pipe a section of about 50 sq. ins. After the hard-pan was reached, the pipes were cleaned out by means of a water-jet and then subjected to heavy pressure by means of a hydraulic ram. They were somewhat over 40 ft. long, and under the pressure of the ram were shortened about ¼ in., springing back to their original position when the pressure was removed. The fact that the top of the pipe returned to its original level showed the compression to be in the metal and not the hard-pan. Mr. O'Rourke.

Charles E. Emery, M. Am. Soc. C. E.—The removal of parts of foundations has been practiced before the work described in the paper, the underpinning of the Washington Monument being an instance, but the latter undertaking was carried on above the level of ground water, and did not present the difficulties inherent to going below water and working in a cramped position. The author's simple and effective methods are very different from those in vogue only a few years ago. When the New York Steam Company's building was erected by the speaker, he could not obtain permission to pile, and was forced to rest the structure on sand. One side of the company's building was on Mr. Emery.

Mr. Emery. good sand, and the foundations presented few difficulties. On the other side the sand was fine and moved easily when wet. At such points the company bought the abutting property with the exception of one building, which had been secured by a speculator and an exorbitant sum charged for it. The tenant of the basement was persuaded, however, to allow work to proceed on his part of the premises, and a suitable foundation was finally built, which carried both buildings. The excavation was extended without pumping a few feet below the water line, and the concrete was deposited under water very carefully. Since gaining that experience, the speaker has had considerable faith in a good concrete foundation well down into the sand, for, although this building settled somewhat, a few vertical cracks near the tops of the walls relieved the inequality of the strains, and no further settlement took place. In one of the large office buildings which was being constructed at the same time on a pile foundation in similar material a number of the main columns sank, carrying the piles down with them, and it became necessary to relieve the load and put in extra columns and inverts to distribute the weights over a larger number of piles.

The pressure per square foot on the sand foundation which sank was approximately $3\frac{1}{2}$ tons per square foot. An attempt was made to reduce the load to 3 tons per square foot, but it was impracticable to rack out sufficiently to accomplish it. The final weights were to have been 4.4 tons per square foot under the columns, 4.25 tons per square foot under the chimney, and 4.2 tons under the side walls, but the building has never been carried to its full height, so that the actual loads do not exceed $3\frac{1}{2}$ tons per square foot at the locations stated. The calculated pressure on the soil under the front wall was only 3 tons, which was rather a disadvantage than otherwise, as that did not sink as much as the other walls and caused a crack through the central arches. H. W. Brinckerhoff, M. Am. Soc. C. E., who was in immediate charge of the work, thinks that if the inverts at some openings in the front had been left out, the settlement would have been pretty nearly uniform.

In erecting a power station at Fifty-eighth Street and Madison Avenue, in New York City, it was necessary to build the structure on the site of an old watercourse known to be filled with quicksand and mud overlaid by 14 to 16 ft. fill of good earth well compacted after a series of years. The building was a temporary one, so the fill was partly excavated and the building founded on the remaining solid earth at a depth of about 10 ft. below the curb, the base of the chimney being carried lower and supported on piles driven as close as possible. The building has four stories and a basement, and although but 5 or 6 ft. of filled material separates it from the mud and quicksand, it has never required bracing, and a crack developed at one rear corner only, which relieved the strain due to a want of uniformity in settling. The chimney has not moved and the station is in good order.

CORRESPONDENCE.

Alfred Noble, M. Am. Soc. C. E.—The writer's connection with the work described in the paper was at first as consulting engineer to advise as to the method of supporting buildings proposed by the author and to outline the detail plans, and afterward as superintending engineer to see the work carried out. The method appearing perfectly feasible, the next question was as to the size of the supporting columns and the manner of securing a proper foundation for them. It was supposed that bed-rock would be found about 35 ft. below the foundations of the adjoining buildings with the probability of a thin layer of overlying hard-pan. There was good reason to suppose that the surface of the rock would be quite uneven. Mr. Noble.

It was at once recognized that where heavy weights were to be carried, facilities must be given for laying bare and leveling the surface of the bed-rock so that a fair, square bearing could be secured for the column. This necessitated the use of compressed air in preparing the foundation, and fixed the minimum inside diameter of the column as that in which a man could work; for the Western Union and Stock Exchange Buildings this was taken 28 ins., giving, with a thickness of 1 in. of metal, an exterior diameter of 30 ins. It was inconvenient to work in so small a cylinder under compressed air, and progress was slow; but the use of compressed air was generally unnecessary until hard-pan was actually reached, it being found practicable to remove nearly all of the quicksand by working a jet continuously while jacking down the cylinders, the quicksand passing off with the overflow.

After pushing the cylinder down to its final bearing on the leveled surface of the rock, a man was again sent inside, and drove steel wedges under the cutting edge wherever possible. As this, however, was far from being a continuous metal bearing, and as, furthermore, it was really a bearing on rock, on an annulus not more than 2 or 3 ins. wide, it was thought proper to limit the unit strain in the cast-iron cylinders to about 5 000 lbs. per square inch. A further consideration to the same end was the fact that during the subsequent sinking of the caissons alongside, the support against flexure afforded by the surrounding quicksand would be somewhat disturbed.

The concrete with which the cylinders were filled was made with a rich Portland cement mortar; at least the first 6 ft. was filled under compressed air. No account was taken of the concrete filling in calculating the strength of the columns. There is no doubt, however, that it added considerably to their strength at the time the caissons were sunk alongside, because during the intervening days (or weeks in some cases), the concrete would have attained much hardness, and by means of the interior flanges of the cylinders a considerable portion of

Mr. Noble. the load would be transferred through it to the bed-rock on the interior of the cylinders. This transfer would be facilitated by a slight yielding of the packing at the joints of the cylinders and of the wedges at the cutting edge.

In the case of the old four-story and basement building, No. 24 New Street, the weight which each column would have to carry was less than could be imposed by the hydraulic jack used in forcing it down. It was, therefore, believed that a series of 10-in. pipes having the necessary section of metal would afford adequate support if sunk by the jack to refusal on the underlying hard-pan. An experimental column showed that the hard-pan was impenetrable under the maximum pressure given by the jack, and the plan was carried out on this basis. The decision as to size of columns in the two cases was made at one and the same time, and the results proved it to be correct.

There was no settlement in the buildings which could not be accounted for by the compression of the material in the columns themselves, and in each case was quite insignificant compared with the usual settlements in buildings founded on earth.

The wall of the Stokes Building has, as the author states, a spread foundation. The surface of ground water is about 2 ft. below it, so that the foundation rests directly upon material which is not quick. This was not important, however, because the excavation in the neighboring lot for the new Queen's Insurance Building was to be carried into the quicksand, and the foundation would surely be weakened.

The cross-section of the lower part of this wall, Fig. 5, shows a remarkable instance of a spread foundation on which the load is not central. The arrangement is obviously one which should produce tension in the vertical face; during the work of sinking the supporting cylinders, conclusive proof was afforded that this existed.

The method described in the paper is particularly applicable where a material capable of supporting a great weight can be reached readily by the use of compressed air. It must be noted that it cannot be carried out without a temporary weakening of the original foundation, a portion of which must be removed. In quicksand the bearing capacity of a neighboring portion will inevitably be somewhat reduced and a little carelessness, permitting an inrush of sand into the cylinder, may cause serious results; but with due care the method is entirely practicable, is economical and should find extended application.

Mr Schenck. A. A. Schenck, M. Am. Soc. C. E.—The author speaks of the necessity of carrying on operations in compressed air in sinking foundation cylinders. This method has been considered necessary in many cases of cylinder settlement, and, of course, in this case those in charge are the best judges. In nearly all cases of cylinder settlement, either the pneumatic process or the plan of pumping out the cylinder in some way appears to be considered necessary for the pur-

pose of excavating or removing obstructions, preparing the bottom, placing concrete, etc. Both the use of compressed air and the use of the pump have disadvantages connected with them besides the expense. Where the material to be removed from the cylinder requires more than mechanical appliances working under water, it will be found both cheaper and better to send down a man in the diving suit much more frequently and generally than is now done, in place of pumping out. Mr. Schenck.

About ten years ago the writer had occasion to sink cylinders 8 ft. in diameter, for piers of a bridge across a western stream. It was impossible to drive piles to a safe depth. By sinking cylinders and excavating within them, it was possible to force the piles to a satisfactory depth. A very much smaller number of piles was required, and solidity and resistance to drift were secured without the expense of solid masonry piers, stone for building purposes being hard to obtain.

The assistant engineer in charge of test borings reported only fine sand to the depth to which it was intended to sink the cylinders. The piers were located on low sand islands or bars, the surface of which was about a foot above extreme low water. An 8-in. centrifugal pump was placed on the sand bar, and used during the earlier part of the work on each cylinder, the material being removed by buckets. As the depth increased, it was found that the pump sucked the finer material from around the cylinder to such a distance that the inflow of water became very rapid. Below a depth of a few feet, also, the material changed to compact gravel with small boulders from 1 to 2 cu. ft. in size, which required hand labor in the cylinders. The latter part of the work was therefore carried on with the diving suit. No professional diver was employed. A diving suit and apparatus were rented, and ordinary laborers sent down. They were allowed higher wages for such work with short hours. There was no trouble in getting plenty of men who would go down under such simple conditions and for moderate depths. The buckets were filled by hand. The shells were sunk until they were considered to be below any scouring action of the river; but the settlement could have been carried much lower without difficulty, had there been anything to justify the expenditure of more time and money. Below the bottom of the cylinders, piles were then driven, not only increasing the safety against scouring, but securing stability by a foundation firmly and deeply rooted in the hard material. The outer circle of piles was driven first.

No attempt was made to cut off the piles and cap them before filling the cylinders with concrete. It was considered that better results would be secured without this. Since the pile tops rise to varying distances in the concrete, there is no horizontal line of cleavage at

Mr. Schenck. which the mass of concrete can tilt on the piles. The concrete mass grips the piles securely, making one rigid column from the bottom of the piles to the top of the concrete; and the stability of the piles in the ground is extended to the whole column.

The concrete was deposited in the water in the column at first by spouting it; but in parts of two cylinders it was thrown into the water as mixed, the water being about 10 ft. deep. Although this method is in violent contradiction of most theories, the results appeared to be fully as good, if not better, than those of usual methods. In fact, it is believed that the concrete so placed was better, and better distributed, and more compactly placed, than any other. The cement, sand and stone appeared to go to the bottom at once in one mass, and as well mixed as when first prepared, and the concrete to diffuse itself much better. The water through which it passed retained very little of the cement. The resultant mass was apparently more homogeneous and solid than if placed in air and rammed.

The river is in a densely wooded country, and carries much drift during floods, including many trees 5 or 6 ft. in diameter, and over 100 ft. in length. Occasionally such trees have broken against the cylinders without tilting or injuring one of them. No settlement of bearings or of the concrete occurred in the cylinders after the filling with concrete was finished.

The shells were of $\frac{1}{4}$-in. plate, in two pieces to the circumference, about 4 ft. high, lap joints, all rivets being $\frac{3}{4}$ in. and spaced 3 ins. The plates were bent to the circle before shipment. All riveting was done on the ground. At first the shells were settled by weighting, but tapping with a pile-driver hammer was afterwards cautiously attempted. It was found that with the riveting stated, it was safe to give a blow of 3 ft. fall of hammer weighing 1 800 lbs., taking care not to continue the blows long after the movement downward had ceased. Two layers of 12 x 12-in. timber, crossed, were laid on top of the unflanged shell. This mode of settling disturbs the surrounding material less than the water-jet. The full lateral stability and frictional effect of the surrounding material is retained. By not pumping out, heavy stresses upon the shell are avoided, and the hundred and one difficulties which come from inviting pressures.

In soft mud, it would be necessary to excavate in the shell some distance below the proposed level of the tops of the piles, to keep the mud from being forced upward during the driving and covering the pile heads. A few minutes' work of a diver will ensure the cleanliness of the pile heads. The placing of concrete should be done slowly at first, so that the cement between piles is given time to settle to a stable bearing and reasonable depth. If the mud itself will not permanently sustain concrete, it will be found that by adhesion to the piles, the concrete will generally come to rest. Where the depth of

mud is too great to allow one length of pile to reach hard bottom, it is possible to go part way with a cylinder, excavate, and then drive single lengths of piles, using a temporary follower. After the shell has been well filled with piles, it will be found that the mud will come into the shell much more slowly; and the piles can be kept clear of it long enough to permit the concrete to be placed on the pile heads. The retention of the water in the shell at all times will tend to keep out the mud. The shell may be of cheap construction where no pressures are created by pumping out. The iron shell may even have a wooden lining to serve as a mold for the concrete, the iron being removed and used again, and iron protection being left only at heights where protection from erosion is necessary. This method of not pumping out depends on the engineer's willingness to let the concrete do its own capping, leveling and fitting upon the piles. The Mr. Schenck.

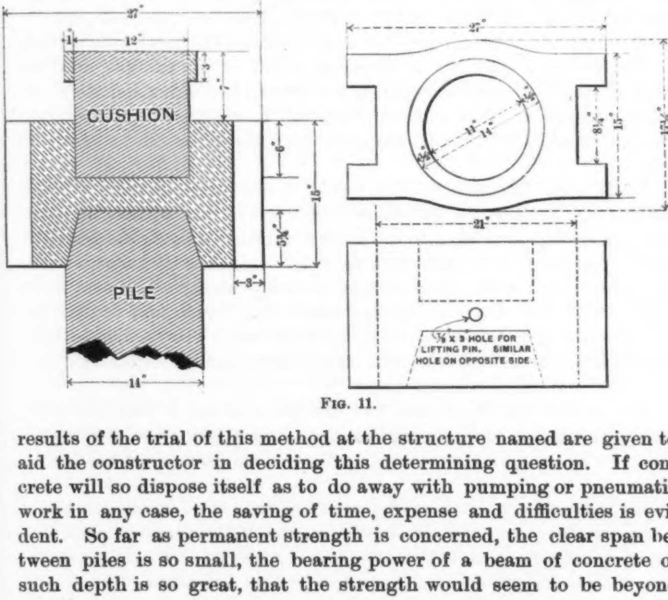


FIG. 11.

results of the trial of this method at the structure named are given to aid the constructor in deciding this determining question. If concrete will so dispose itself as to do away with pumping or pneumatic work in any case, the saving of time, expense and difficulties is evident. So far as permanent strength is concerned, the clear span between piles is so small, the bearing power of a beam of concrete of such depth is so great, that the strength would seem to be beyond question.

It is well to note in this connection that it is often a loss rather than a gain to penetrate through a compact layer of material in order to reach solid rock. If the rock be uneven, this layer acts as a natural concrete deposit to distribute the weight, and its frictional hold of the rock is very valuable. It is often better to enlarge the area of the

Mr. Schenck. proposed cylinder to suit such material than to go down in search of a sloping rock, with the expensive leveling that will be necessary when the shell reaches it.

Where there is no underlying material that can be penetrated by the piles, so as to secure vertical stability to the piles in very soft mud, some other system must be used that will give stability against tilting.

It is desirable that where piles are loaded with concrete without cutting off, the pile heads should be uninjured to any great extent. The writer therefore submits a design of cast-iron follower and cushion which has been in use on the New York Central and Hudson River Railroad some years, under direction of Mr. W. D. Otis, General Roadmaster. This device, Fig. 11, not only enables piles to be driven into hard material otherwise impenetrable, but at the same time preserves the pile head perfect. The pile heads are dressed to fit the follower. The writer has seen large groups of piles driven into hard-pan, yet the heads of the whole group were left as perfect as if they had been turned.

The cylinder type of substructure is full of advantages, and has come to stay. At present it is tied too fast to the older and more expensive methods. It is a development of the old Cushing pier, which was not much more than a protective belt placed around a group of piles.

Mr. Thomson. T. Kennard Thomson, M. Am. Soc. C. E.—Having carefully watched the underpinning of the buildings mentioned by the author, and seen how successfully his method works, the writer thinks he has not sufficiently emphasized the difference between this and other arrangements for supporting a wall. This system gives a permanent and safe foundation, while the others act more as falseworks, which may or may not be safe while in use, and may or may not be safely removed, especially if there is quicksand underneath, without affecting the adjoining buildings.

The author has illustrated two distinct systems of working; first, the pipe system, which can only be used under favorable conditions; and, second, a system of large cylinders, which can be used anywhere.

The first consists of a pipe pile or column, in which the diameter is too small to permit an observation of the bottom, and the pipe is driven to refusal, or until the pressure exerted by the jack is greater than the subsequent load to be carried by that individual pipe.

Of course, an electric light and mirror or camera could be used, but this would be of little value, as a small boulder might be mistaken for bed-rock. The pipes are generally made strong enough when empty to carry the load, and are then filled with concrete, which, although adding greatly to the strength, is not depended upon. When made of steel, there is, of course, no effectual way of preventing ulti-

mate destruction by rust, while the objection to cast iron is that it is liable to breakage under the jack. A thin steel pipe could be forced down, and a cast-iron column afterwards placed inside of it, having the intervening space filled with concrete or grout, which would make a cheap and permanent foundation. Mr. Thomson.

When the question of underpinning the old building at No. 24 New Street came up, the author suggested the pipe scheme. As doubt was expressed as to its feasibility, a gas-pipe driver was designed and built, and a 2-in. gas pipe was driven down with the aid of a water-jet, where the first support was proposed. This boring indicated that there was nothing but quicksand, clay and sand between the surface and hard-pan. The absence of boulders was what had been hoped for, because these pipes can only be depended upon when they are driven to hard-pan or rock; for while the resistance to the jack might indicate that there would never be enough pressure from the walls to cause further penetration, still, if the pipe were stopped on a boulder under which lay quicksand, the sinking of pneumatic caissons nearby might draw the material from under the boulder and allow the wall to settle. A preliminary boring of this nature should be made for each individual pipe that is to be used. The subsoil of a greater portion of lower New York is similar to what was found at the new Commercial Cable Building, which is an ideal location for this kind of underpinning.

The borings mentioned having removed all doubts, it was calculated that a 10-in. pipe of $\frac{3}{8}$-in. metal, weighing 40 lbs. per foot, would be strong enough for a temporary support. A number of these were obtained in the market at once, in lengths of about 5 ft., with butt joints and outside couplings. A smooth outside joint would have been preferred, but could not be obtained so readily. It was supposed that there might be some difficulty in dislodging the material under the pipe, so a cast-iron shoe or cutting edge was designed, having connections for three $\frac{3}{4}$-in. gas pipes, and a system of holes to distribute the water from the $\frac{3}{4}$-in. feed pipes all around the cutting edge. The first 10-in. pipe had one of these shoes, which worked well, but it was found that a single gas pipe dropped from the top and connected with a hose was ample, so the expensive shoe and three fixed gas pipes were dispensed with in the rest of the 10-in. pipes, which had the cutting edge stiffened by an ordinary coupling. It was also found convenient to have a temporary short section of pipe, about 3 ft. long, screwed on top of each permanent section as it was being forced down. This short section had three vertical slots, about 3 ins. wide and $1\frac{1}{2}$ ft. long, to permit the gas pipe and hose to be worked up and down without disturbing the jack. A connection was made lower down for the overflow. The quicksand passing through the overflow pipe was so fine that it looked like mere dirty water until allowed to settle. An architect on another building who tried to pump water from under

Mr. Thomson. his foundations thought he was only raising dirty water, but after pumping twenty-four hours or so, without lowering his water level to any extent, he stopped, and subsequently had a cave-in.

The following is the writer's report to the contractors on the sinking of the first 10-in. pipe at No. 24 New Street:

"The first cylinder of the ten proposed to support the old wall (nine were used) has six sections of 5 ft., and one of 4 ft., ⅜-in. metal, having 12 sq. ins. section, and weighing 40 lbs. per foot, with patent couplings on the outside and butt joints. On the bottom there was a cast-iron shoe 1½ ins. thick, with small holes for jetting connected with three ⅜-in. gas pipes to supply the water with.

"A hole was dug in the ground about 3 ft. deep, and two 5-ft. sections placed in position under the jack, at 10.56 A.M., Saturday, March 28th. In three minutes the pipes had been driven 8 ins. Numerous stops were made to plumb the pipe, which at 12.11 P.M. had been driven 2 ft. 6 ins.; by this time whenever the jack was in use, the pressure was taken off by the two pine shores which braced the 12-in. beams. The old wall was so rotten that there was no support for these temporary 4 ft. I-beams, and it was considered unsafe to cut 4 ft. out of the wall without temporary wooden shores. On filling the pipe with water again, it escaped under the shoe.

"The third length, 5 ft., was added at 2.15 P.M., and the pipes disconnected with the shoe, after which the pipe was kept filled with water by shoving a pipe down from the top. The overflow was heavily laden with quicksand. The pipe was driven about 11 ins. between each shift of the jack in from six to ten minutes, all the way down to hard-pan.

"The fourth length was screwed on at 4.09 P.M., and driven home at 5 P.M., when work stopped for Sunday.

"Monday, March 30th, work started at 7 A.M., and the fifth length was down at 8.55 A.M. The sixth and seventh lengths were under water at 11.20 A.M. By this time every application of the jack lifted the beams off of both shores. The jack was removed, and the sand jumped out of the pipe, after which the jack was again put in place and worked to its full capacity, 60 tons, without further sinking. The previous 2-in. boring showed 34 ft., and 34 ft. of 10-in. pipe having been driven with the above results, the presumption was that rock or hard-pan had been reached. The caissons afterwards sunk besides these pipes proved that they were resting on hard-pan. When the men got accustomed to the work, the remainder of the pipes were put down from 33 to 35 ft. in five or six hours."

In this building there was no difficulty in removing the old foundation wall to insert the pipes, jacks, etc., because the original mortar was not much better than powder.

In order to increase the strength of some of the 10-in. pipes, 8-in. pipes were placed inside after sinking, concreted and grouted.

The second system has cylinders of large enough diameter to permit a man entering, and, if necessary, blasting out boulders until bed-rock is reached. These cylinders under the Western Union Building were 30 ins. in diameter outside, and were forced to hard-pan by two jacks and a water-jet when the jacks were removed, a small air lock

being put in their place to permit a man to enter and excavate the hard-pan. Sometimes the jacks would be replaced, and the cylinder forced down farther. Mr. Thomson.

The writer certainly does not wish to be understood as recommending for use near any heavy building any kind of a coffer-dam which is pumped dry without a compressed air chamber. So far these pneumatic caissons have only been forced down to hard-pan or rock by means of a hydraulic jack under old buildings, the weight of whose walls give sufficient resistance to the jacks; but by arranging a system of heavy movable weights, the same system might be used to advantage for new foundations, and it would seem that something of the kind is wanted where the cost of ordinary pneumatic caissons is prohibitive.

Under the present New York building laws, if pneumatic foundations are used, and the foundations carried to rock, the pressure exerted on bed-rock must not exceed 30 000 lbs. per square foot, or 25 000 lbs. on good concrete. Now this often requires such a large cylinder that the expense prevents the owner from attempting to go to rock at all, and he decides on a pile foundation instead, which is certainly cheap, as he is allowed to load each pile with 40 000 lbs., and place them as close together as he can. In fact one of the highest buildings in New York is being founded on piles, which are so close together that they are practically in contact, and when cut off, cannot be much more than 10 ft. long. Moreover a whole bunch of these piles is most decidedly out of plumb. Would it not be very much better to leave the piles out entirely, and put the money in a good thick bed of concrete over a larger surface, or better still, have a non-corrosible column carried down to bed-rock, even if the pressure on good rock was 80 000 to 100 000 lbs. per square foot, instead of putting 40 000 lbs. on a 5-in. pile?

Mr. Schenck advocates divers instead of compressed air, but he must have been exceptionally fortunate in his selection of divers. Work in compressed air is generally under the supervision of an engineer, which is certainly a more reliable plan than to rely on the word of an ordinary diver. The writer has met one diver whose word he could trust, and that man would recommend compressed air every time a good piece of work was desired.

There was a bridge where the coffer-dams leaked so badly that it was decided to dump 5 ft. of concrete over the entire bottom. The divers were paid $40 a day to look after this, but as the coffer-dams continued to leak and the divers reported the surface of the concrete dead level, it was decided to start the masonry on a timber platform and gradually sink it until it rested on the dead level concrete. The Chief Engineer, however, thought he would have a look at the concrete first, so he rigged up several more pumps, and by hard work

Mr. Thomson. managed to lower the water long enough to examine the concrete, which proved to be anything but level, in fact there was one hole about 5 ft. wide by 20 ft. long and from 4 to 5 ft. deep. The coffer-dams were eventually made water-tight and all the concrete blasted out.

Mr. Saunders. W. L. SAUNDERS, M. Am. Soc. C. E.—It may perhaps interest some members to know what kind of a machine is that which is shown in Plate I. It is, perhaps, but an incident in connection with this important work to know by what means the cutting away of the wall was accomplished. The author used for this purpose a gadder, the upper part of which is shown in the illustration, a machine about which, perhaps, little is known except by those members who may be familiar with marble quarrying.

It will generally be admitted that the author has described a very substantial method of underpinning. It is in no sense a cheap method, and anything which aids in reducing the cost of such work is worthy of notice. To cut away old brick masonry, especially that laid in cement, is usually a slow and expensive operation. By means of this gadder the author outlined the space which he wished to cut away by a series of holes driven in a manner which is illustrated by the perforations separating postage stamps. The rock drill is mounted upon a special frame which consists mainly of a cast-iron base carried on four wheels, to the end of which is pivoted or hinged a standard or post. This standard carries the rock drill through a carriage which moves upon parallel guides and by means of which the drill is raised or lowered to any desired position. The standard is capable of a varied adjustment from a vertical position to one very much inclined. By means of this adjustment, together with the movement of the drill through the carriage on the standard, a line of holes may be inserted in any position or at any angle against a wall. The frame is so designed that it is stiff enough to resist the thrusts of the drill while working even near the top of the post, Compressed air, which is always available in a work of this kind, furnishes the power to run the drill and the holes are driven with great rapidity. Once the wall is thoroughly perforated it is an easy matter to break away the intervening masonry.